

# An Evaluation of the Ability of RFID Tags to Withstand Distribution of Fresh Produce in the RPC Pooling System

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## SUMMARY

This study focused on the ability of radio frequency identification (RFID) tags applied on reusable plastic containers (RPCs) to withstand repeated abuse due to physical distribution and storage environment related hazards. It also studied the effect of the chemical cleaning environments that RPCs are commonly exposed to in the pooling/rental systems commonly used to distribute fresh produce. RPCs are being successfully deployed in the US, Europe and Asia to ship fresh produce from growers to retailers. The increasing demand for traceability and tracking of fresh produce from 'farm to fork' requires these containers to be monitored and identified in the food supply chain, and RFID technology provides one of the solutions. This study compared eight commercially available RFID tags mounted on RPCs for use in fresh produce distribution and subjected them to repeated physical and climatic cycles representing the distribution and cleaning environments, and their effective 'read' capabilities were tested.

## INTRODUCTION

Radio frequency identification (RFID) has generated much interest ever since Wal-Mart announced its initiative to implement RFID technology in its supply chain in 2003.<sup>1</sup> This started a series of initiatives among other major retailers, such as Albertsons, Metro and Target.<sup>1</sup> Almost concurrently, the Department of Defense took the initiative to implement RFID technology in its Defense Logistics Agency (DLA) supply chain.<sup>1</sup> Over the past decade, the cost reduction in RFID technology, collectively with improvements in performance and global standards, has enabled its widespread use in the logistical planning and operation of supply chain processes in the manufacturing, distribution and retail industries.

RFID involves the use of electronic tags with integrated circuit chips that can store data. The tags, affixed to the asset, transmit their data via low power radio waves to reading systems that are tuned to the same frequency, enabling transactions to be recorded and tracked. A typical transmission sequence consists of a system handshake, data modulation and data encoding.<sup>2</sup> A form of RFID tags includes battery powered tags (or 'active'), but 'passive' (or 'backscatter') tags are slated to be more widely used. Tags in this category derive all their power from the reader's signal. Nearly all RFID systems operate on one of four frequency bands, namely low frequency (125–134 kHz), high frequency

(13.553–13.567 MHz), ultra high frequency (UHF, 400–1000 MHz) and microwave (2.45 GHz).<sup>2</sup> The read range typically increases with increase in frequency. Low frequencies are commonly adopted for applications such as livestock tracking, card key, and access control. High-frequency RFID is more flexible and is utilized for applications such as baggage handling. UHF is the most widely used RFID band due to its robustness and read range. Key applications for the UHF band are materials management and supply chain tracking. The microwave band features in applications such as electronic toll collection and railroad monitoring.

The application of RFID technology as related to packaging, although widely adopted, is still fraught with performance concerns.<sup>3</sup> The optimum performance of this combination depends on many factors, such as environmental, geometry of the product/package and packaging materials and/or packaged product.<sup>4</sup> A recently published review paper highlights several consumer-level RFID applications and initiatives taken by some of the global leaders in the apparel, consumer goods and fresh produce industries.<sup>5</sup> This research highlights the promise of this technology to provide end-to-end real-time visibility of all items moving through the supply chain. Several other studies have evaluated topics ranging from readability issues, tag orientation and location, effect of product type and packaging, among others.

A recently published study evaluating the effects of item composition, tag inlay design, reader antenna polarization, power and transponder orientation on the dynamic coupling efficiency of back-scatter UHF RFID concluded that the use of this technology for item-level identification of food requires multi-parameter assessment beforehand.<sup>6</sup> It was found that the effect of water content was far more significant than metallized packaging; tag placement in relation to the packaging material was significant in relation to coupling capabilities; reader antenna polarization was significant with circular polarization being better than linear polarization at tag detection; and the tag inlay design was significant in relation to the coupling capabilities of the RFID system.

A study focusing on RFID tag orientation and package contents was conducted by Clarke *et al.*, and revealed that only 25% of the tags on a pallet load of shipping containers holding bottled water could be effectively read, whereas dry rice filled jars had a higher read at 80.6%.<sup>7</sup> The study concludes that it is difficult to achieve 100% reads even with empty boxes. This suggests the limitation of implementing passive RFID tags on packages with certain types of contents. The study that used Class 1 Gen 1 tag technology did not discover a significant effect based on tag orientation.

A separate recent study considered package content, tag location, fork lift speed, pallet pattern and their interaction as the variables.<sup>8</sup> It was observed that readability greatly varies for different product-package systems. A pallet load of paper towels produced near 100% readability rates followed by bottled water and carbonated soda cans. It was observed that slower forklift truck speeds provided better tag readability. The best pallet patterns for tag readability were dependent on the product-package type. The best pallet pattern for bottled water was column stack and that for carbonated soda was interlocking.

The effect of conveyor belt speeds on the readability of tagged cases of consumer

products was observed in a recent research.<sup>9</sup> Conveyor belt speeds of 61, 122 and 183 m/min were used in this study to analyse the readability of tagged cases of paper towels, bottled water and carbonated beverage cans. The study concluded that besides the paper towel cases, the conveyor belt speed had a considerable effect on the read rates of the tagged cases.

Another study evaluated the effect of moving palletized loads of the same tagged consumer product cases, as in the above-mentioned research, through a warehouse portal at speeds of 1.6, 8.1 and 16.1 km/h, respectively.<sup>10</sup> It was observed that fork truck operating speeds had very little effect on read rates. Speeds over 15 km/h reduced the tag read rates by about 10% as compared to slower speeds of around 2 km/h.

Although a limited amount of published research is available on readability, orientation, location, product/package system, etc., none has delved on the RFID tag durability. Reusable plastic containers (RPCs) are being widely used in the automotive and fresh produce industries. First introduced to the US retail trade in 1996 by Wal-Mart and HEB (Texas-based retailer), RPCs have become prevalent at all major retail outlets.<sup>11</sup> Recent deployment of these reusable containers has been conducted at Stater Bros. (2006), Kroger (2006), Harris Teeter (2008), etc.<sup>11</sup>

With the recently reinvigorated environmental stewardship goals set in place by most consumer goods manufacturers and distributors, the employment of RPCs has been rapidly growing in the packaging industry. A recent Life Cycle Inventory study comparing RPCs with single-use display-ready paper corrugated trays summarized its findings as follows: the RPCs require 39% less total energy, produce 95% less total solid waste and generate 29% less total greenhouse gas emissions.<sup>12</sup>

RFID technology promises to provide unrealized benefits when applied to RPCs, provided the tag is able to survive multiple trips during distribution. Therefore, the study of the durability and reuse of RFID tags on RPCs is of great importance to meet the supply chain distribution and sanitation requirements for fresh produce. A recent report on the deployment of RFID tags designed for single use could be used in multiple-use scenarios without significant deterioration in performance if positioned optimally on RPCs.<sup>13</sup>

RPCs are typically leased or rented through a third-party pooling system for distribution by the manufacturing, distribution and retail industries. They are usually sent to the growers, who in turn fill them and send them to the distribution centres/retailers. The retailers, who often use the filled RPCs directly for display, are not generally responsible for the rental amount or lost RPCs; the growers are. Figure 1 describes the pooling system approach commonly used by the fresh produce industry. As can be seen in the figure, in addition to repeated transportation and handling cycles, any RFID tags along with the containers undergo repeated stress due to high temperature washing with chemical detergents (sanitization), all of which impact the 'read' capabilities of RFID tags.

## MATERIALS AND METHODS

The distribution testing protocol established for this study was adopted from test methods/procedures proposed by the American Society for Testing and Materials (ASTM)<sup>14</sup> and International Safe Transit Association (ISTA).<sup>15</sup> The protocol was developed to determine the ability of several types of RFID tags placed on RPCs to withstand the abuse of industrial distribution and sanitization for fresh produce applications. The purpose of this project was to evaluate the readability of the tags after being subjected to the anticipated hazards and conditions through a series of laboratory-simulated shipping cycles. Five shipping cycles were conducted on eight types of RFID tags on the same RPC type. All eight tags were placed on 10 RPCs providing 10 replicates for each simulated distribution cycle. The details of the test methodology for this study are described in the section Testing Procedure.

### *Reusable plastic containers*

The RPCs for this study were obtained from Polymer Logistics Inc., (Riverside, CA, USA). Model 6416 (Figure 2) was used for this study, which measures 60 x 40 x 6.5 cm<sup>3</sup> with a nesting height of 33 mm and tare weight of 1.50 kg. The injection-moulded RPCs were made of polypropylene and had a recommended load capacity of 15 kg.

### *RFID tags and hardware*

The following eight UHF Class 1 Gen 2 tags were used in this study (Figure 3). The detailed specifications for the tags are available from the distributor's website.<sup>16</sup>

- Intermec IT65 large
- Intermec IT65 small
- Alien 9450
- Laminated Alien 9450
- Alien 9554
- Laminated Alien 9554
- Alien 9654
- Laminated Alien 9654

These tags were elected because they are specified to provide the optimal performance in conjunction with RPCs or environments containing water and metal.

The encapsulated Intermec (Everett, WA, USA) tags are rated to perform in harsh industrial applications and temperatures ranging from -40 to 121°C. The Alien Technology (Morgan Hill, CA, USA) tags (non-laminated) used the Fasson® S490 inlay adhesive, a general purpose permanent adhesive.<sup>17</sup> The Alien tag models 9450, 9554 and 9654 were also laminated on both sides using Xyron Inc.'s (Scottsdale, AZ, USA) 22 cm ezLaminator lamination machine. No heat was used to laminate the 0.08 mm thick polyethylene film to the tags. To attach the laminated and encapsulated tags to the RPCs, 2.54 cm wide and 3.18 mm thick double-sided 3M (St. Paul, MN, USA) model 4408 foam tape was used.

Alien Technology's Alien 9900 Gen 2 Enterprise RFID reader and ALR-961 1-CR

circular polarized antenna were used in this study.<sup>17</sup> Alien Gateway 10.1.1.10 middleware was used to collect all data. All tests were performed at 0% attenuation of the reader. Four ALR-961 1 circular polarized antennas were used since they are less sensitive to the tag orientation and sufficed the read distance requirements for this project. The portal used in this project is shown in Figure 4.

### *Testing procedure*

A simulation of the physical and climatic distribution environment for typical fresh produce shipments in a RPC pooling environment was conducted. The failure criteria adopted for this simulation were functional damage to the RPCs, RFID tags dislodging from the RPCs or fatal damage to the RFID tags, whichever occurred first. The surviving RPCs and tags were continued through the simulation until 10 cycles were completed. With the eight types of tags applied on a set of 10 RPCs, a total of 80 RPC-tag combinations were included in this research. Figure 5 below summarizes the simulated environment for this research.

**Refrigerated conditioning.** Tagged containers were conditioned for 48 h at a temperature of 5°C ( $\pm 2^\circ\text{C}$ ) and relative humidity of 85% ( $\pm 5\%$ ), as specified by ASTM D4332 for each distribution test cycle.<sup>14</sup>

**Vibration testing.** The sinusoidal vibration test, also known as the ‘sweep and dwell’ vibration test, was employed as per ASTM D999.<sup>14</sup> This test is typically used to assess the performance of a container, with its interior packing and means of closure, in terms of both its strength and of the protection it provides its contents when it is subjected to vibration such as it experiences in transportation.<sup>14</sup> It is not intended for determining the response of products to vibration for product design purposes.

Ten tagged and loaded RPCs were secured in a column pattern on a Lansmont model 1800 electro-hydraulic vibration tester (Lansmont Corp., Monterey, CA, USA), and a frequency ‘sweep’ from 3 to 100 Hz was performed to identify the resonant frequency where the maximum vertical displacement of the packages is observed. The vibration test setup is shown in Figure 6. The sinusoidal frequency identified through this test was 4.3 Hz, at which it ‘dwelled’ for 15 min. The peak amplitude (0 peak) for this test was held steady at 0.5 g throughout the test. Figure 6 shows the simulated vibration test.

**Drop testing.** The filled containers were subjected to six drops representing one cycle in accordance with Schedule A, Handling – Manual and Mechanical, ASTM D4169.<sup>14</sup> The RPCs were filled with simulated loads of 15 kg, representing the maximum recommended shipping weight by the manufacturer. The RPCs were tested based on the total container weight as described in ASTM D5276 at assurance level I. The drop height selected for all drops was 53.3 cm. The drop sequence consisted of the following sequence: one drop on the bottom face, two drops on the adjacent bottom edges, two drops on the diagonally opposite bottom corners and one drop on the bottom face.

**Sanitization process.** Reusable containers such as RPCs, when used for fresh produce distribution, need to be cleaned and sanitized (often with a dilute chlorine or bleach solution) by a documented procedure before reuse to remove decay-causing organisms and

sand and dirt that can injure the product. 18

After a set of conditioning, vibration and drop tests representing simulated distribution, an industrial wash cycle was performed in order to evaluate the post-wash performance. A Manitowoc Foodservice (New Port Richey, FL, USA) TempStar model door-type industrial dishwashing machine was employed for washing, rinsing and drying of the tagged RPCs. The erected RPCs were sanitized one at a time in this machine using Palm Plus Dishwashing liquid soap (Colgate-Palmolive Company, New York, NY, USA). The wash cycle, rinse time and dwell time for this process were 45, 11 and 2 s, respectively. The operating temperatures for washing and rinsing were 66°C and 75°C, respectively.

**Tag readability testing.** Upon completion of both the simulated distribution and sanitization wash cycles, as described in Figure 5, the RPCs were tested for tag readability. A pallet loaded with the tagged RPCs was moved through the portal with reader antennas on both sides at a speed of 8.05 km/h. The reads were scored on a 'read' or 'no read' basis. At each stage, the pallet was passed through two different times, first with the RPCs facing in one direction and then rotated 90°. This was done because the tags were placed on both the small faces of the RPCs. Five cycles of the distribution and sanitization protocol were conducted.

## RESULTS AND DISCUSSION

A total of 80 tags were processed and tested through five distribution and sanitization cycles, each as described in the section Testing Procedure. A complete report of the survival data is shown in Table 1. Tags are designated as encapsulated (Intermec IT 65 L and Intermec IT65 S), laminated (ALN 9450, ALN 9554 and ALN 9654) or non-laminated (ALN 9450, ALN 9554 and ALN 9654) in the table, and the same designations are used through the discussion. There were two failure modes recorded during testing. Tags either became separated from the container (lost tag) or became unreadable. Lost tags were dropped from further testing. None of the encapsulated units ( $n = 20$ ) failed for readability or lost tags during testing.

None of the laminated tags were lost during testing. For non-laminated tags ( $n = 30$ ), 76.7% of the tags tested fell off by the end of the fifth wash cycle. Only 3.33% (1/30) failed by the end of the second wash cycle. The third wash cycle saw a significant increase to 20% lost tags (Figure 7). For non-laminated tags, there seemed to be no significant relationship between specific tag numbers and tag retention.

With respect to readability, only 6.7% (2/30) of the laminated units failed for readability during all testing (Table 2). None of the laminated units failed for readability until the fourth wash cycle.

Of the non-laminated tags that were not lost, 33.3% were unreadable by the end of the third wash cycle (Table 3). The reduced percentage for the fourth and fifth wash cycles is misleading because 76.7% of the tags had fallen off by the fifth wash cycle. The starting number of non-laminated tags was 30. The percentages shown in Table 3 are based on the number of remaining (not lost) tags.

Most read failures occurred after sanitization. There were only two instances where

tags failed for readability after distribution stress. These were both non-laminated tags, and the failures occurred in cycles 1 and 3 (Table 1). The failure of one of the ALN 9450 tags directly after the first distribution stress (cycle 1) may be indicative of an early quality failure rather than totally stress related.

Overall, the data show that encapsulation is the most reliable method for protecting RFID tags. Lamination is a viable protection method, especially if the number of sanitization cycles is limited. Unlaminated tags suffered extensively from both failure modes during testing. The unlaminated tags tested are not viable for use in RPC pooling systems.

## CONCLUSIONS

- All RFID tags evaluated can be read after the first cycle of physical, climatic and chemical handling for shipping and sanitation.
- Drops, vibration, high temperature washing and detergents collectively degrade the RFID tag identification capability when reused.
- Only three of the eight RFID tags that were commercially available at the time of this study survived more than ten cycles of reusability when subjected to shipping and cleaning requirements for fresh produce.
- In general, the process of sanitization (chemical and climatic) is more detrimental to tag readability as compared with transportation and handling (physical).
- The ideal protection method for reuse of RFID tags on reusable containers is by encapsulation of the tag.

## ACKNOWLEDGEMENT

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## FIGURES AND TABLES

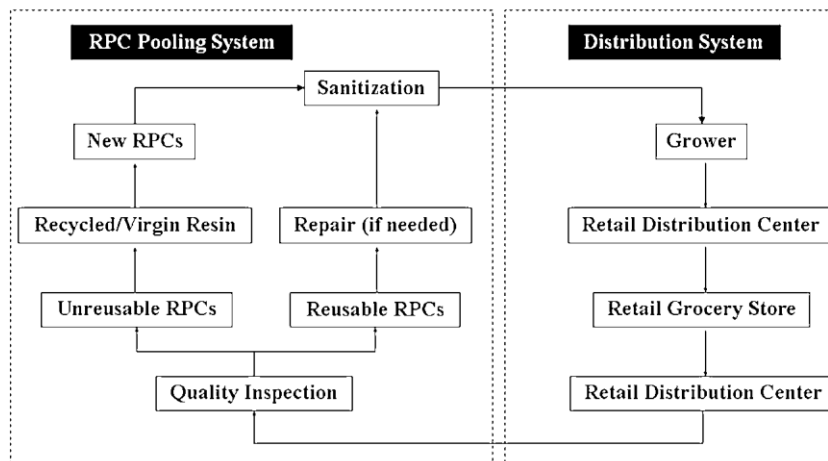


Figure 1. Typical RPC pooling and distribution.



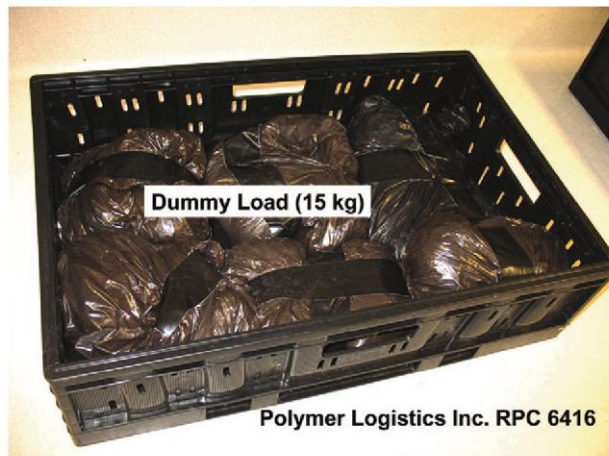


Figure 2. RPC, model 6416.

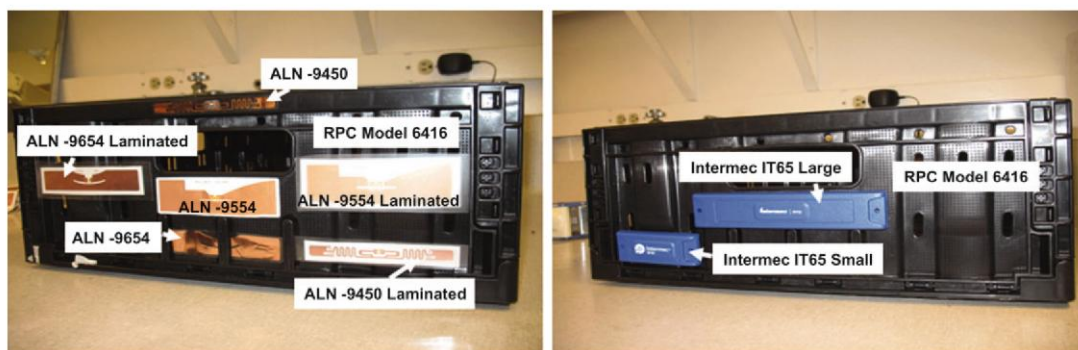


Figure 3. RFID tag placement on RPCs.

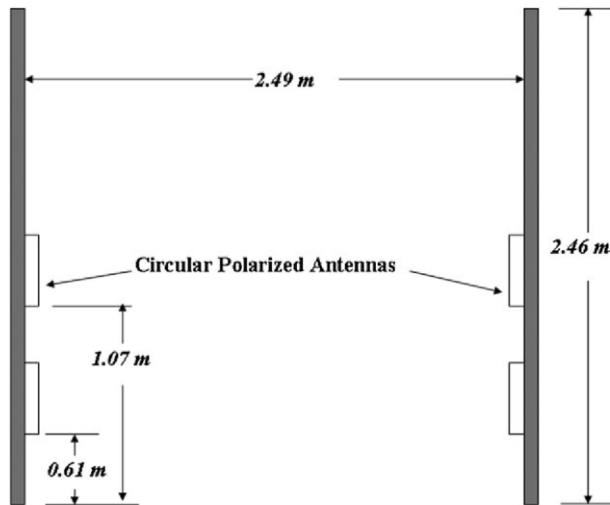


Figure 4. Portal setup.

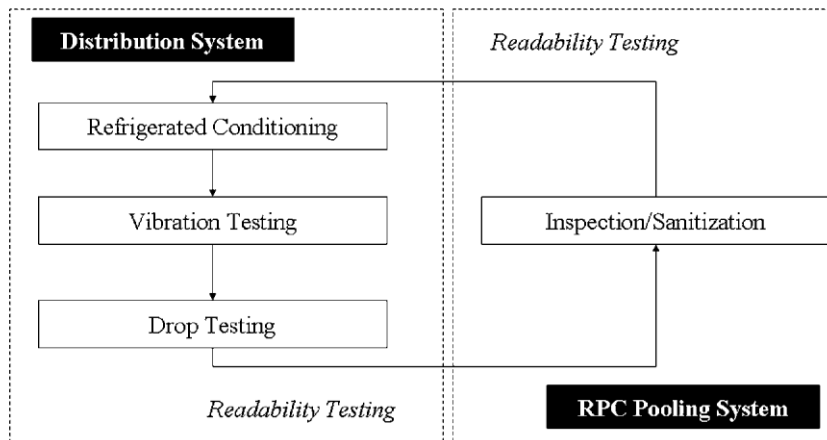


Figure 5. Test protocol used for each cycle.

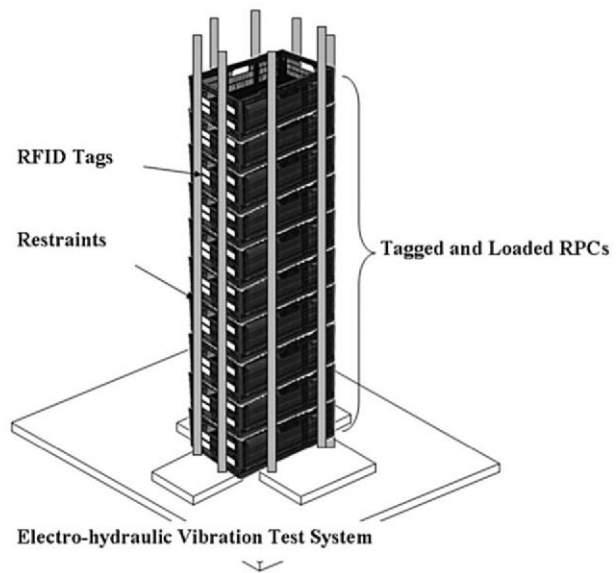


Figure 6. Vibration test setup.

Table 1. Summary of survival data for all tags tested.

a. Tags successfully read

PN	<i>n</i>	Pre- test	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
			Dist.	Sanit.	Dist.	Sanit.	Dist.	Sanit.	Dist.	Sanit.	Dist.	Sanit.
Encapsulated												
Intermec IT65 L	10	10	10	10	10	10	10	10	10	10	10	10
Intermec IT65 S	10	10	10	10	10	10	10	10	10	10	10	10
Laminated												
ALN 9450	10	10	10	10	10	10	10	10	10	10	10	9
ALN 9554	10	10	10	10	10	10	10	10	10	10	10	10
ALN 9654	10	10	10	10	10	10	10	10	10	9	9	9
Non-laminated												
ALN 9450	10	10	9	9	9	9	9	7	7	5	5	3
ALN 9554	10	10	10	9	9	7	6	4	4	4	4	2
ALN 9654	10	10	10	10	10	8	8	5	5	4	4	2

b. Tags successfully adhering to the RPCs

PN	<i>n</i>	Pre-Test	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
			Dist.	Sanit.	Dist.	Sanit.	Dist.	Sanit.	Dist.	Sanit.	Dist.	Sanit.
Encapsulated												
Intermec IT65 L	10	10	10	10	10	10	10	10	10	10	10	10
Intermec IT65 S	10	10	10	10	10	10	10	10	10	10	10	10
Laminated												
ALN 9450	10	10	10	10	10	10	10	10	10	10	10	10
ALN 9554	10	10	10	10	10	10	10	10	10	10	10	10
ALN 9654	10	10	10	10	10	10	10	10	10	10	10	10
Non-laminated												
ALN 9450	10	10	9	9	9	9	9	8	8	5	5	3
ALN 9554	10	10	10	10	10	10	10	7	7	4	4	2
ALN 9654	10	10	10	10	10	10	10	9	9	5	5	2

Note: Highlighted cells indicate the number of read failures or lost tags. The cells marked in bold are instances where readability first failed after distribution simulation as opposed to after sanitization stress.

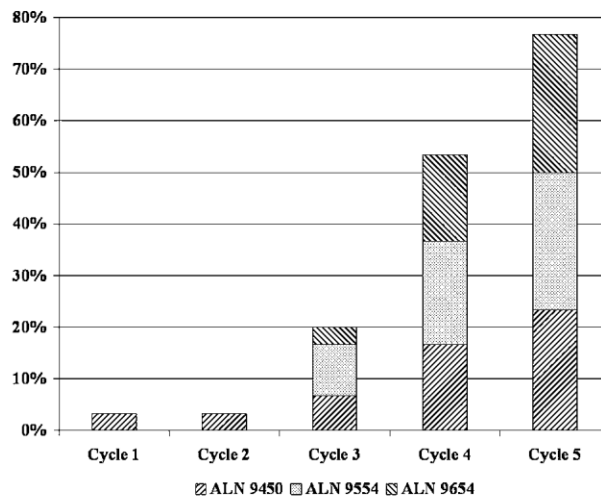


Figure 7. Cumulative lost tag failure percentage for non-laminated tags ( $n = 30$ ).

Table 2. Cumulative read failure percentage for laminated tags.

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
ALN 9450 L	0	0	0	0	3.30
ALN 9554 L	0	0	0	0	0
ALN 9654 L	0	0	0	3.30	3.30
Total	0.00	0.00	0.00	3.30	6.70

Table 3. Cumulative read failure percentage for remaining non-laminated tags.

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
ALN 9450	0	0	0	0	0
ALN 9554	3.40	10.3	12.5	0	0
ALN 9654	0	6.90	16.7	7.10	0
Remaining (n)	29	29	24	14	2
Total	3.40	17.2	33.3	7.10	0.00